MODEL FM-140A

DIGITAL CONDUCTIVITY METER

INSTRUCTION MANUAL

MAGNAFLUX

MODEL FM-140A

DIGITAL CONDUCTIVITY METER

THE MAGNAFLUX MODEL FM-140A DIGITAL CONDUCTIVITY METER IS A LIMITED RANGE MEASURING INSTRUMENT SPECIALLY CALIBRATED WITHIN THE RANGE OF 23% TO 62% IACS. EXCEPT FOR A FEW CIRCUIT CHANGES, IT IS ELECTRICALLY AND OPERATIONALLY VERY SIMILAR TO THE STANDARD MODEL FM-140.

Manufactured by:

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Form #20923

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SECTION 1

GENERAL DESCRIPTION

The Magnaflux Model FM-140 Digital Conductivity Meter is an electronic measuring instrument which uses electromagnetic induction to produce eddy currents in nonferrous metals to directly measure electrical conductivity within the range of 23% IACS to 62% IACS. Rapid, direct conductivity measurements can be made on a wide range of metals and alloys. The instrument can also be used to measure changes in physical properties related to electrical conductivity such as hardening, annealing, changes in alloy, heat treating, aging, etc.

Resistivity may be calculated from conductivity in percent IACS (percent of the International Annealed Copper Standard @ 20° C), by using the following equations:

$$\text{Resistivity} = \frac{172.41}{\%\ \text{IACS}}\ \text{Microhm - cm}$$

$$= \frac{1037.1}{\%\ \text{IACS}}\ \text{Ohm-circ mil/ft}$$

Alternating current flowing through the probe coil induces eddy currents in the metal to be measured. The eddy current density in the test material is a function of electrical conductivity. These induced currents, in turn, cause changes in the probe electrical characteristics, and the reaction of a bridge circuit to these changes is detected and amplified.

The amplified bridge unbalance signal is then linearized, compared with a known voltage reference, converted to a digital representation, and displayed on the front panel digital indicator.

SECTION 2

SPECIFICATIONS

Range	23% to 62% IACS.
Accuracy	±2% of reading ±0.1% IACS at 20° C.
Resolution	0.1% IACS.
Readout	3-1/2 digits, 0.43", seven-segment LED display with fixed decimal point. Automatic display blanking when probe lifted from test part.
Probe	Standard probe 7/16" diameter with ceramic wear shoe. Probes interchangeable. Replacement probe requires only minor internal adjustment to the instrument.
Lift-Off	Lift-off compensation circuit with front panel control to permit measurement on moderately rough surfaces and to compensate for minor probe positional changes.
Calibration	Two panel mounted calibration samples. Separate front panel control for each sample.
Batteries	Two rechargeable 7.2 volt nickel-cadmium batteries with built-in transformer type charger. The instrument can be operated on line while charging the batteries. Approximately 10 hours continuous operation before recharging is necessary with normal use.
Line Operation	The FM-140 can be operated from its internal rechargeable batteries or from the 115/230 VAC, 50/60Hz line source. The instrument is normally wired for 115 VAC service. For 230 VAC operation, the charger special transformer primary tap must be used (refer to schematic diagram). Line power consumption approximately 10 watts.
Case	High-impact shock resistant case with adjustable tilt handle, 2.7" (68.6mm) x 8.4" (213.4mm) x 9.0" (228.6mm) deep.
Weight	4-¼ pounds (1.93 kg) excluding probe and line cord.

SECTION 3

FRONT PANEL COMPONENTS AND CONTROLS

ON-OFF Switch	Two-position bat handle toggle switch. Battery recharging is accomplished with the switch in the OFF position.
Charge	Red indicator lamp within the battery charger circuit. The lamp indicates that line voltage is applied to the charger circuit.
Probe	BNC type receptacle for connection of the measuring probe to the instrument.
Lift-Off	Multi-turn control used to compensate the probe to prevent moderate surface roughness or nonconducting oxide scale from affecting the accuracy. This control is adjusted as part of the instrument calibration procedure.
High & Low	Multi-turn controls for calibration of the instrument. Associated with the controls are two case mounted calibration samples. Each control is adjusted with the probe placed on the respective high or low range calibration sample.
Course High	Multi-turn screwdriver adjustment to provide additional calibration range needed for a major change in operating conditions such as a large change in ambient temperature or probe replacement.

SECTION 4

GENERAL OPERATING INSTRUCTIONS

The FM-140 can be calibrated in line or battery mode using the two case mounted calibration samples. The instrument must be calibrated before use, and calibration should be checked at frequent intervals during testing. Calibration should always be checked when a change in ambient temperature occurs.

The calibration samples and probe must always be kept clean. Dirt on the samples or particles imbedded in the probe face can result in improper seating of the probe on the sample causing measurement errors.

The following steps must be followed to properly calibrate the FM-140:

1. Turn the instrument on and allow a few minutes warmup.

2. Check the battery indicator and charge the batteries if the meter pointer is at or near the red zone.

3. Place the probe in the center of the high calibration sample and adjust the LIFT-OFF control if necessary to obtain a reading on the display.

4. Insert a .003" - .004" thick paper or plastic shim between the probe and high calibration sample and note the display reading.

5. Pull the shim from between the probe and sample and note the direction of the display reading change. Then turn the LIFT-OFF control in a direction to cause the display reading to change in the same direction.

6. Repeat Steps 4 and 5 until the same display reading is displayed with and without the paper interface.

7. Adjust the HIGH control so the display reads the high calibration sample value with the probe held firmly against the center of the high sample.

8. Adjust the LOW control so the display reads the low calibration sample value with the probe held firmly against the center of the low sample.

9. Repeat Steps 7 and 8 until complete calibration is obtained.

10. Measurements are made by holding the probe firmly against the surface of the material to be tested and reading the electrical conductivity on the display.

NOTE

The COURSE HIGH control can be used to center the HIGH control during initial calibration or to compensate for a change in ambient temperature. Where centering of the HIGH control is required, set the HIGH control at mid-range and adjust the COURSE HIGH instead of the HIGH control in Step 7.

SECTION 5

MEASUREMENT PRECAUTIONS

5.1 Calibration

The instrument must be calibrated before use and calibration should be checked at frequent intervals during testing. Each instrument is furnished with two calibration samples to provide a reference point near each end of the conductivity range. Both the conductivity in % IACS and an identifying number are engraved on each sample, and both samples are affixed to the case top to prevent their becoming lost or misplaced.

It is recommended that a permanent record of the sample identifying numbers be kept since only the samples supplied are authorized for use with each instrument. If the calibration samples are lost or damaged, similar samples, even if they are engraved with a conductivity value, may not be arbitrarily substituted. The instrument must be returned to the nearest Magnaflux Service Center when replacement of the calibration sample(s) is necessary.

5.2 Conductivity Measurements

Measurements can be made over a conductivity range of 10% to 108% IACS on non-magnetic materials only. Accurate measurements cannot be made below 10% IACS even though a display reading may be observed on certain low conductivity materials and alloys. The instrument accuracy noted in Section 2 is specified only over the range of 23% to 62% IACS.

When tests are made, the probe must be firmly held against a flat surface with a minimum diameter of approximately 1 inch. The probe surface must be clean and free of inclusions to assure proper seating on the test material. The probe face is protected from wear by a ceramic wear shoe. A certain amount of care should be exercised in handling the probe. For maximum probe life, avoid sliding or scraping the probe on the test specimen or subjecting the probe face to impact.

Measurements are independent of thickness, provided the materials is thicker than the eddy current "infinite thickness". This thickness is defined as the depth at which the eddy current density is a sufficiently small fraction of the surface value so that variations in the metal thickness have negligible effect on the conductivity readings. Infinite thickness is approximately .030 inch for materials having a conductivity of 100% IACS and .100 inch for materials having a conductivity of 10% IACS.

Thin nonconducting layers of oxide and scale, or moderate surface roughness do not materially affect the accuracy of the instrument. However, it must be kept in mind that probe lift-off compensation is effective over a limited range, so that attempted measurements on excessively rough surfaces can result in erroneous readings. When in doubt about the suitability of the specimen surface condition, it is recommended that a section of the test part surface be ground smooth and flat and comparison tests be made.

5.3 Temperature Effects

For maximum accuracy, the instrument and test part should be temperature stabilized at 20°C (68°F). The accuracy is not significantly degraded at temperatures slightly above or below this value provided the unit is calibrated at the ambient temperature, and both the calibration samples and the test part are at the same temperature.

Electrical conductivity is a function of the temperature, in general decreasing as the temperature is increased. For temperature in the vicinity of room temperature (0°C to 40°C), the conductivity is expressed by the following relation:

$$g_T = \frac{g_{20}}{1 + a(T - 20)}$$

where T is the actual temperature in degrees C, g_T is the electrical conductivity in % IACS at the actual temperature, g_{20} is the electrical conductivity in % IACS at 20°C, and a is the temperature coefficient of resistivity for the material.

A change in temperature of 1°C will change the conductivity of a sample by 0.4% of its value, taking the average temperature coefficient as .004 as an approximation for most pure metals. The calibration samples supplied with the FM-140 Conductivity Meter have their conductivity accurately determined at 20°C so that if the calibration samples are not at the same temperature as the part to be tested, and assuming that the calibration samples and test parts possess equal or nearly equal temperature coefficients, the instrument will indicate the conductivity at 20°C even though the actual temperature may be different. For this reason, when measuring a material that is not 20°C, it is important that the calibration samples and the metal being measured be at the same temperature for accurate results.

Variations among the temperature coefficients of the calibration samples and the test part can introduce an additional source of error. This error is negotiable when the ambient temperature and the temperature of the test part are both close to 20°C but can become significant when the temperature deviates from the above value by 10°C or more.

The temperature coefficient of resistivity for nearly all metals depends on the amount of impurities and the alloying elements, if any, used. For example, the temperature coefficient of resistivity of pure copper is approximately .004 per degree C, whereas the temperature coefficient of a common copper alloy such as brass is typically .002 per degree C. Where extreme accuracy of readings is required, therefore, it is important that the material temperature coefficient of resistivity be taken into account whenever the ambient temperature is not near 20°C.

In view of the above-mentioned temperature effects, it is always recommended that for a maximum accuracy, conductivity measurements be made in a location where the temperature is relatively constant and as close as possible to 20°C (68°F) and with the probe, calibration samples, and test part all well stabilized to the ambient temperature.

5.4 Line Operation and Battery Test

The model FM-140 may be operated in either line or battery mode. To operate from line power, simply connect the power cord supplied to the line receptacle at the rear of the case. With the switch in the ON position, the CHARGE lamp will be on indicating that the charger circuit is supplying the battery with a trickle charge. The instrument will function normally when powered from the A.C. line.

When operating in the battery mode, the battery test meter should be checked occasionally and the line cord connected to recharge the batteries if the meter pointer is within the red zone of the meter scale. In most cases the instrument will still be operational when the meter pointer is in the extreme upper portion of the red zone. However, as the battery continues to discharge further, erratic operation, display instability, rapid change in calibration, and eventual dimming of the display will result.

SECTION 6

SERVICE AND MAINTENCE

6.1 General Maintenance

The FM-140 is built with high quality components and materials and should give long reliable service. However, care should be taken so that the instrument is not subjected to shock of handling abuse. All servicing should be performed by quality electronic technicians only.

Condition of the calibration samples and probe are most important. The samples must be kept clean and free from scratches, as particles of dirt or surface disfigurement may cause errors in calibration and measurement. The probe should be checked frequently and cleaned when necessary to remove particles of dirt or metal imbedded in the surface.

Probe failure will generally be caused by an open-circuited coil, indicated by a blanked display or by a shorted coil, indicated by a fixed display reading.

6.2 Battery Maintenance

The FM-140 is powered by two self-contained rechargeable nickel cadmium batteries, capable of being recharged many times and not adversely affected by long periods of inactivity, having an indefinite storage life. The battery cells are completely sealed and leakproof.

The batteries are rated for approximately 10 hours continuous operation from the "fully charged" state before recharging is necessary. The need for recharging is indicated by the meter pointer position with the switch in the ON position. When the meter reading is at, or within the red zone, the batteries have reached the lower limit for proper operation of the instrument and must be recharged.

The FM-140 contains a built-in transformer type charging circuit to reduce shock hazards. The charger circuit limits the charging current to an average value less than 10% of the battery rated capacity, and recharging "from the red zone" is accomplished in 10 to 14 hours (overnight) with the switch in the OFF position. Charging current is also available to the batteries with the switch in the ON position, but at a reduced rate.

Although nickel-cadmium batteries are capable of withstanding overcharging for extended periods of time without damage, continuous overcharging for long periods should be avoided for optimum battery performance. Under normal ambient conditions, the batteries can be continuously overcharged for months or even years with little effect on service life, provided the charge rate is, as in the FM-140, within the design limitations of the cells. The main effect of extended overcharging is an eventual loss of cell capacity. This, however, is a reversible failure and full capacity can usually be restored by a deep discharge followed by a full recharge.

Continuous operation of the instrument from the A.C. line with the switch in the ON position, such as in an automatic system, is acceptable since the charging current is reduced to a low value. Under these conditions, an occasionally (every few months) full discharge -- recharge cycle is recommended.

Battery life cannot be accurately predicted since it depends on many variables. However, the number of discharge-charge cycles is claimed by most battery manufacturers to be typically 1000 cycles under normal service conditions and at a discharge of rated capacity. The average current demand from the batteries is less than 100% of rated capacity, and the meter red line corresponds to approximately 85% of capacity removal so that discharge is terminated well before complete capacity removal. Under these conditions, improved cycle life can be expected.

CAUTION

The polarized line cord supplied with the FM-140 must be plugged into a three wire (grounded receptacle) system. Any extension cord used with this instrument must also be a three wire cord connected to a properly grounded three wire receptacle.

6.3 Probe Replacement

Probes for the FM-140 are field interchangeable. The following procedure must be followed to properly calibrate the instrument to a replacement probe.

1. Remove the four rubber feet attaching screws and lift off the top cover.

2. Set slide switch S101 (left center of P.C. board) to the balance position.

3. Remove integrated circuit (I.C.) U121 from its socket (right center of printed circuit board viewed from front of unit) and plug it into socket designated U102 (lower right). When installed, circular dot on top of integrated circuit must be at upper right corner.

4. With probe in air and away from any conducting metal, adjust R114 (right center of printed circuit board) and panel LIFT-OFF control simultaneously for a minimum reading on the display (typically less than 20.0).

5. Replace integrated circuit U121 in its original socket with dot at upper right corner.

6. Return S101 to the SIG position and replace cover, rubber feet, and attaching screws.

7. Lift-off compensate and calibrate as outlined in Section 4 using the COARSE HIGH control to center the HIGH control as noted.

SECTION 7

CIRCUIT DESCRIPTION

7.1 Theory of Operation

Refer to Figure 1, Model FM-140, Block Diagram. The various circuits can be represented by the functional blocks shown. The power supply and battery charger circuits are not shown on the Block Diagram.

The oscillator generates a sinusoidal waveform, approximately 60 KHz, which is connected to the amplifier and bridge driver circuits. The bridge is configured in such a way that the probe and reference coil are in adjacent bridge arms with an internal balance control and the front panel LIFT-OFF control used to balance the resistive and reactive components of the bridge complex impedance. LIFT-OFF compensation is obtained by adjusting the bridge reactive component to that point on the impedance plane where the bridge output voltage changes in amplitude, but not in phase, for a moderate change in probe-to-sample spacing. For a probe impedance change caused by a change in material conductivity, however, the bridge output voltage changes in both amplitude and phase.

The amplified bridge output voltage is connected to a zero-crossing detector, providing an input signal to the phase detector circuit independent of amplitude but whose phase relationaship with respect to the oscillator signal is a function of sample conductivity. A reference signal, also derived from the oscillator, is connected to a second phase detector input through a phase shift circuit. The output of the phase detector is a DC voltage directly proportional to the phase angle difference between signal and reference inputs. Its magnitude depends on the setting of the HIGH and COARSE HIGH calibration controls and is a nonlinear function of conductivity.

The phase detector output voltage is amplified, with the amplifier gain determined by the setting of the panel LOW calibration control. The linearizing circuit and scaling amplifier shown on the block diagram are necessary to present to the digital voltmeter (DVM) circuit a DC voltage linearly proportional to conductivity and correctly scaled so that the DVM circuit input voltage is directly related to the measured conductivity by a known scale factor.

The complete DVM circuit consists of the analog-to-digital (A/D) converter, decoder, driver, and display circuits. The A/D converter converts the input DC voltage to 3-1/2 digit multiplexed BCD format, and the decoder and segment drivers connect the strobed digit data to the front panel LED display.

Blanking circuitry is included to automatically blank the display when the probe is lifted from the test sample to reduce the average current drain from the battery. Display blanking also occurs when an A/D converter over range condition exists, such as when the probe is placed on a steel or other highly magnetic sample.

7.2 Circuit Components

A description of the main FM-140 circuit components, corresponding to the functional blocks shown on the block diagram, is given below. All 100 and 200 series components are located on the main printed circuit board. All 300 series components are located on the front panel.

Oscillator
U101 and associated passive components comprise the complete oscillator circuit. The oscillator produces in-phase sine and triangular waveforms at TP1 and TP2, respectively. Oscillator frequency is determined by the values of C103 and C105.

Driver
Q101 and Q102 form the amplifier and buffer, while Q103, Q104, and Q105 are combined to form the complementary bridge driver circuit. Bridge excitation voltage is connected to TP3.

Bridge
The probe, reference coil L101, LIFT-OFF control R301, and internal balance control R114 are the main elements of the bridge circuit. Operation of the bridge circuit is described in Section 7.1.

Bridge Amplifier
Differential amplifier U102 provides the necessary gain to condition the bridge output voltage.

Zero-Crossing Detector
Comparator circuit U109 generates a square wave 180° out of phase with the bridge amplifier signal and independent of its amplitude. The comparator output is buffered by U107 and connected to one input of the phase detector circuit.

Phase Shifter
Comparator U106 and the panel HIGH and COARSE HIGH calibration controls make up the phase shift circuit. The amount of phase shift is determined by the point on the oscillator triangular waveform where the comparator changes state and the HIGH control setting establishes the threshold voltage at pin 3 of U106. The phase shifted square wave output is buffered by U107 and connected to the phase detector.

Phase Detector
The output of dual flip-flop U108 (pin 13) alternately changes state in response to the positive-going edge of the signal and reference inputs. Referenced to ground, U108 output is set positive by the leading edge of the reference input pulse (pin 11) and reset by the leading edge of the signal input pulse (pin 3), providing at pin 13 a positive pulse of constant amplitude whose pulse width is equal to the time phase difference between the reference and signal waveforms. The flip-flop output is then integrated by R156 and C123 so that the DC voltage developed across C123 is directly proportional to phase difference.

DC Amplifier

U119 and U120, connected in the noninverting configuration, provide the necessary amplifier gain determined by the setting of the LOW calibration control.

Linearizing Circuit

U113 thru U118, along with internal controls R167 through R174 and R177 through R184, form an analog segmental linearization circuit where the nonlinear voltage versus conductivity function is approximated by a number of linear segments. Eight linearizing sections are used to reduce the periodic deviations from a straight line function to a negligible level. U113 through U116 are connected open loop as comparators with R167 through R174 determining the comparator reference voltages. As the input voltage (TP7) changes, successive comparators change state. Each comparator then successively turns on analog switches U117 and U118 permitting current to flow through R188 to supply the necessary correction by increasing the output voltage (TP16).

Scaling Amplifier

U121 and U120 are connected in the noninverting mode with amplifier offset and gain internally adjusted to provide a scaled input voltage to the DVM circuit.

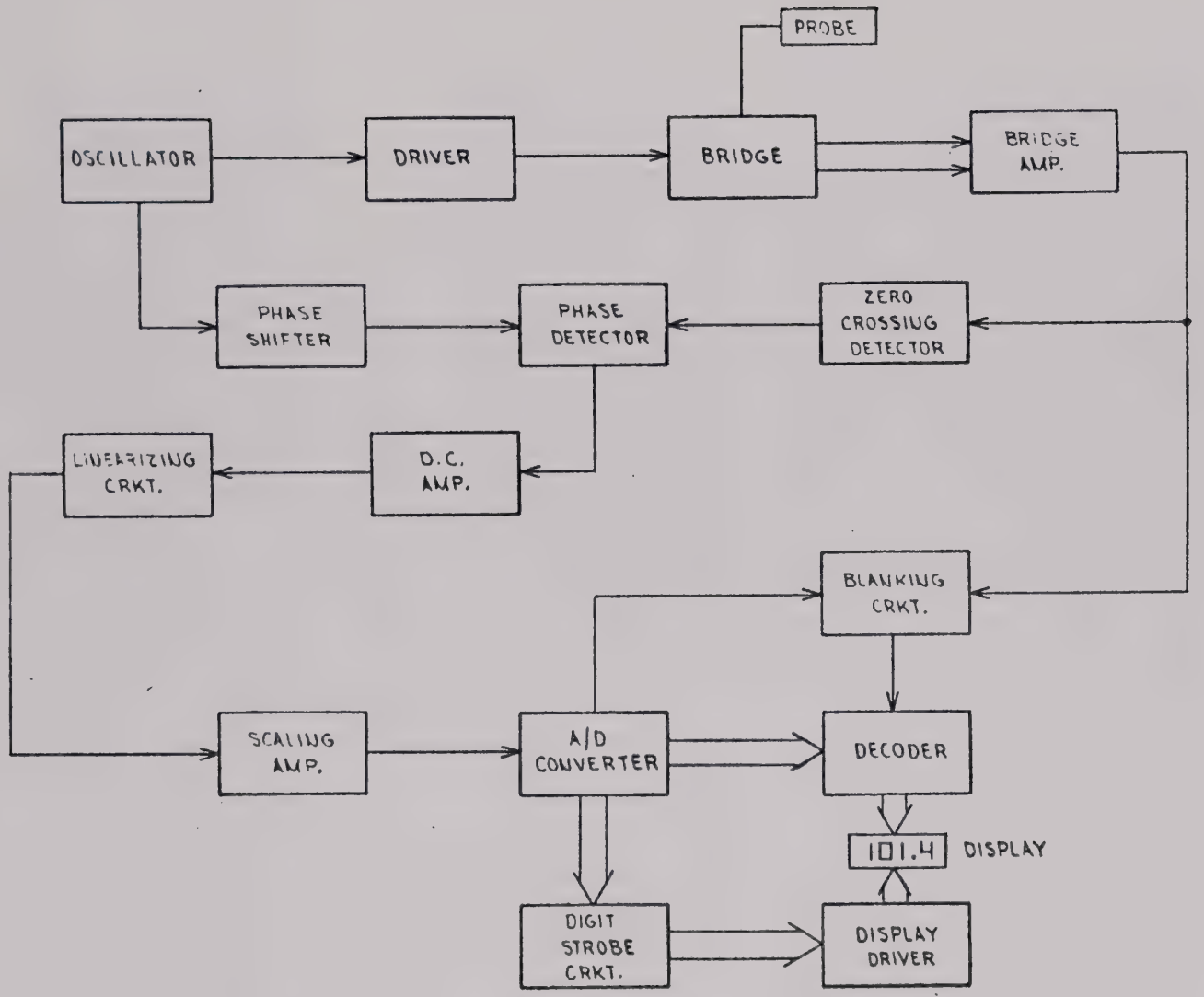

FIG. 1
MODEL FM-140 DIGITAL CONDUCTIVITY METER
BLOCK DIAGRAM

JMSK-121378

EQUIPMENT WARRANTY LIMITS

MAGNAFLUX Corporation warrants our equipment to be first class in every respect as to workmanship and material. Should any part prove defective, excluding X-ray inserts and tubes which are covered on separate warranty, within one (1) year after shipment for equipment or within three (3) months after shipment for ancillary items such as transducers, probes, and test coils, due to materials not as specified by the purchaser and/or MAGNAFLUX Corporation or due to improper workmanship, we will furnish, without charge to the purchaser, replacement of said defective part, materials, or repair parts F.O.B. shipping point. Any such replacement or repair is warranted for the balance of the original warranty or 90 days, whichever is longer. Should the purchase price and/or the order include the services of a MAGNAFLUX erection or installation supervisor, the warranty period shall be for one (1) year from the initial placed-in-operation date, but in no event to exceed fifteen (15) months from the shipment date of such equipment. There is no warranty if equipment is not operated in accordance with instructions provided by MAGNAFLUX Corporation.

The foregoing shall not apply to equipment that shall have been altered or repaired after shipment to you by any one except our authorized employees, and the company will not be liable in any event for alterations or repairs except those made with its written consent. On parts and components not of our manufacturer, only the manufacturer's warranty to us is extended. This paragraph does not cover ordinary wear and tear, corrosion, erosion, or improper handling or storage after leaving our point of shipment. Expendable or perishable items such as vacuum tubes, fuses, lamps, and batteries are not covered by this warranty. This warranty is non-assignable beyond the original purchaser without the written consent of MAGNAFLUX Corporation.

LIABILITY LIMITATIONS

MAGNAFLUX Corporation will in no event be liable for any special, incidental or consequential damages whatsoever, and our liability under no circumstances will exceed the contract price for the goods for which liability is claimed. Its obligations as stated in its limited warranty are in lieu of all other obligations and liabilities including negligence and/or omissions and all warranties, or merchantability or otherwise, express or implied in fact or by law. These equipment warranty and liability limitations paragraphs state our entire and exclusive liability and buyer's exclusive remedy for any claim of damages in connection with the sale or furnishing of goods or parts, their design, suitability for use, istallation or operation.

ADDITIONAL INFORMATION AND MANUAL CHANGES

The latest electronic developments are always incorporated at MAGNAFLUX into the instruments as soon as they are tested and become available.

Sometimes printing and shipping schedules will not permit including the latest changes into the manual. The schematic numbers in this manual may have a suffix letter differing from the bill of material (parts list). This is indicative of a change to the circuit since the last manual revision. In any case, the schematic is correct and up-to-date, and the nameplate number on the item should match the schematic number for that item.*

*If no addendum follows, this manual is correct as printed.

FOR SERVICE, CALL THE SERVICE CENTER NEAREST YOU:

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Form No. S-8507 Rev. 4-13-84

Electronic Instrument Warranty

WARRANTY

When used in accordance with the instruction manual and under normal operating conditions, each instrument manufactured by MAGNAFLUX Corporation is warranted to be free from defects in material, workmanship and capable of operation within published specifications for a period of one year after delivery to the original purchaser. Transducers, probes and test coils, are warranted for 90 days. MAGNAFLUX will, at its sole option, replace or repair (on its premises or at an authorized repair station) without charge to purchaser, any instrument, transducer, probe or test coil which proves defective (subject to warranty limitations mentioned below) within its warranted period. Any such repair or replacement is warranted for the balance of the original warranty or 90 days (30 days for transducers, probes and test coils) whichever is longer.

Any defective instrument, accessory or peripheral equipment (transducers, probes, etc.) to be returned to MAGNAFLUX (or to an authorized repair station designated by MAGNAFLUX) for repair must be properly packed with all transportation charges prepaid. Any and all instrument, accessory or peripheral equipment replacement will be at the sole discretion of MAGNAFLUX.

The foregoing warranty does not apply to any instrument, accessory or peripheral equipment that has been subject to negligence, accident, misuse or customer improper installation or operation or that in any way has been tampered with altered or repaired other than by an authorized MAGNAFLUX service organization or an employee thereof.

Warranty coverage is not extended to expendable items such as lamps, fuses and batteries. Instrument accessories such as oscilloscopes, recorders, etc., will be covered under the original manufacturer's warranty as issued to MAGNAFLUX, or for 90 days, whichever is longer.

THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

This is an original purchaser warranty and is not transferable without the written consent of MAGNAFLUX Corporation.

To register this warranty, please fill out and mail the enclosed registration card.

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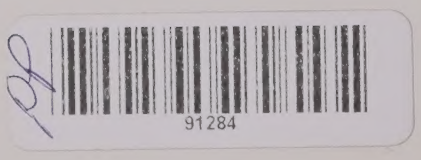

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